ERDEC-TR

Domestic Preparedness: Sarin Vapor Challenge and Corn Oil Protection Factor (PF) Testing of Powered Air Purifying Respirator (PAPR) Systems and Cartridges

Authors: Lee E. Campbell
Alex G. Pappas

March 1999

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
MAR 1999		**00-03-1999 to 00-03-1999**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Domestic Preparedness: Sarin Vapor Challenge and Corn Oil Protection Factor (PF) Testing of Powered Air Purifying Respirator (PAPR) Systems and Cartridges	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Army Research, Development and Engineering Command,Edgewood Chemical Biological Center,5183 Black Hawk Road,Aberdeen Proving Ground,MD,21010-5424**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**21**	

Disclaimer

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorizing documents. These findings are not intended to endorse or certify any of the commercials products mentioned in this report.

Preface

The work described in this report was authorized under the Expert Assistance Program for CBDCOM (SBCCOM) Program Director for Domestic Preparedness. The use of trade or manufacturers names in this report does not constitute an official endorsement of any commercial products. This report may not be cited for purposes of advertisement.

This report has been approved for public release. Registered users should request additional copies from the Defense Technical Information Center; unregistered users should direct requests to the National Technical Information Service. This report is tailored for the first responder.

Acknowledgements

The authors wish to thank Sabrina Edwards, Dawn Minor, Michael Wasserman, Carroll Cook, Raymond Lins for their laboratory expertise during the conduct of agent testing.

The authors would also like to thank Gary Hiob, William Fritch, Stephen Chase, Stephen Kaminsky, Karen Torchia, Linda Strickler, Jeff Hofmann, Malcom Little, and MacDonald Goodman for their help and expertise in PF testing. The authors also acknowledge Frank DiPietro and Anthony Saponaro for managing the equipment acquisition and test scheduling necessary to accomplish the testing in a timely manner.

The authors are grateful to the following members of the Expert Review Panel for Personal Protective Equipment Testing, for their constructive reviews and comments:

Dr. Kent Hofaker, Battelle Memorial Institute, Columbus, OH
Dr. Jimmy L. Perkins, University of Texas School of Public Health, San Antonio, TX
Dr. Annetta P. Watson, Oak Ridge National Laboratory, Oak Ridge, TN
Dr. Edward T. Zellers, University of Michigan School of Public Health, Ann Arbor, MI

Table of Contents

1. Introduction

Under the Domestic Preparedness (DP) Expert Assistance Personal Protective Equipment (PPE) Evaluation Program, the Edgewood Chemical and Biological Center (ECBC) was tasked to perform testing of Commercial Powered Air Purifying Respirator (PAPR) Systems and Cartridges. Three tests were performed: (1) Chemical agent breakthrough testing of PAPR cartridges (specifically the organophosphorus nerve agent GB, known as Sarin), (2) Combined Sarin-challenge testing of cartridges and facepiece facial seals using a manikin headform equipped with simulated-breathing pumps, and (3) Corn oil Protection Factor (PF) testing of PAPR Systems using human subjects. The PF testing examines the face seal only, the breakthrough testing with Sarin examines the cartridge adsorption efficiency only, and the combined test examines both under high concentration challenge conditions. The chemical agent testing was done by Chemical Evaluation Laboratory, Surety Team, Engineering Directorate. The PF testing was done by the Mask Fit Test Facility, Non-Surety Team, Engineering Directorate.

2. Objectives

The first objective of the task was to determine the protection potential of the PAPRs against the organophosphorus nerve agent, Sarin (GB). GB is the standard nerve agent used in military testing. It is the most volatile of the nerve agents and hence more suitable for vapor testing. There are presently no standardized qualification procedures developed for these types of applications. Therefore, a draft version of procedures developed by the U.S. Army Chemical Agent Safety and Health Policy Action Committee (CASHPAC), and methods and requirements established by the National Institute for Occupational Safety and Health (NIOSH) were used as guides in developing the test procedures used for the DP applications. The test procedures are described in subsequent sections of this report. The testing was done by Chemical Evaluation Laboratory, Surety Team, Engineering Directorate.

The second objective was to perform Protection Factor (PF) testing of the PAPR systems being challenged by a corn oil aerosol. This is a standard Army procedure used by all military services. The testing was done by the Mask Fit Test Facility, Non-Surety Team, Engineering Directorate.

3. PAPR Description

PAPRs from six commercial suppliers were obtained for this task. These suppliers are listed in Table 1. With the exception of 3M, all the suppliers produce cartridges that are equipped with North Atlantic Treaty Organization (NATO) threads, and their systems use two or three cartridges, which may be either commercial or military C2 and C2A1 cartridges. The 3M system uses only one large 3M cartridge with a proprietary thread. All the cartridges use activated carbon as the sorbent material, and use a HEPA filter for particulate screening. PAPRs were the tight-fitting variety, that is, the facepiece makes a tight seal against the face of the wearer. All the PAPRs are rated at 6 cubic feet per minute (cfm), 170 liters per minute (L/min), with a fully charged power pack. Cartridges are attached to the case of the motor blower. When the blower is activated, air is pulled

through the cartridges and discharged through a breathing tube to the facepiece. The clean air flows through the breathing room (the space between a wearer's face and the facepiece) of the facepiece, through the orinasal mask (nosecup) and out the exhalation valve. When the air flow is 4-6 cfm through the respirator, a positive pressure is maintained inside the facepiece. A person wearing the respirator is able to breathe clean air from the supplied air stream without overbreathing the supply when engaged in normal activities.

The basic requirement for PAPR selection is that it be NIOSH-approved and provide protection against organic vapors and particulates. The organic vapor and particulate protection are deemed necessary for chemical and biological agents, respectively. After review of NIOSH-approved PAPRs , only six manufacturers were identified who provide PAPRs with a combination of organic vapor and particulate protection. The models selected are listed in Table 1.

Table 1. Selection of PAPRs for Test

PAPR	Cartridge	NIOSH Approval No.	Contaminant Protection*
KASCO Venus T8	ZAP3	TC-23C-1811	8,9
MSA Optimair 6A	GMC-H	TC-23C-1056	1-5,8-10,12
Neoterik TF3	NP2532	TC-23C-1529	1,4,8-11
Racal BE7	AEP3	TC-23C-0647	1,2,4,5,8,9,11,12
Survivair 540084	158300	TC-23C-1053	1,2,4,5,8-12
3M GVP-4M	GVP-443	TC-23C-1478	1-9,11,12

* The contaminants are identified as follows.

1. Asbestos-containing dusts and mists
2. Chlorine
3. Chlorine dioxide
4. Dusts, fumes, mists and radionuclides
5. Hydrogen chloride
6. Hydrogen fluoride
7. Hydrogen sulfide
8. Organic vapor
9. Particulates
10. Pesticides
11. Radon Daughters
12. Sulfur dioxide

4. Chemical Agent Testing

a. Sample Preparation.

Before the cartridges were tested against Sarin, they were pretreated by passing 50% Relative Humidity (RH) air through them at 80°F for 6 hours. This pretreatment was used for all cartridges, whether the cartridges were to be tested separately or as part of a PAPR system.

b. Sarin Vapor Challenge Concentration.

The Assigned Protection Factor (APF) for commercial air-purifying respirators with full facepiece, positive-pressure to chemical canister, tight-fitting facepiece and a high efficiency filter is 125. All the PAPRs tested in this project were of this description. For negative-pressure respirators with the same features, or for PAPRs operating with power off, the APF is 50. The protection factor is derived from the ratio between an aerosol challenge concentration and the aerosol concentration inside the facepiece. Commercial air-purifying respirators are intended for use only in chemical agent concentrations lower than the maximum use concentration (MUC), which is commonly determined as the Threshold Limit Valve (TLV) or Permissible Exposure Level (PEL) times the Assigned Protection Factor (APF) of a respirator. The PEL (equivalent to airborne exposure limit, AEL) for Sarin is 0.0001 mg/m^3 (AR385-61, table 2-3, 28 February 1997), expressed as an 8-hour time weighted average (TWA), which is the average exposure limitation for a normal 8-hour workday and a 40-hour workweek to which nearly all unmasked workers can be exposed, day after day, without known adverse health effects. Given an APF of 50 for the PAPRs tested for this project, the MUC for Sarin is 0.005 mg/m^3 (50 APF x 0.0001 mg/m^3 AEL).

In order to test conservatively, a high challenge concentration relative to the MUC of Sarin was selected to test both the PAPRs and the cartridges. The MUC for Sarin is 0.005 mg/m^3; a challenge concentration of 300 mg/m^3 was selected for the challenge concentration, which is 5-6 orders of magnitude higher than the MUC. This is similar to the CASHPAC draft requirements for testing cartridges, which is 200 mg/m^3 of DMMP (dimethylmethylphosphonate, a simulant for Sarin). Cartridges are tested with constant flows for a period of 60 minutes. Thus, the CT protection (concentration times time) indicated by the test would be 300 mg/ m^3 x 60 minutes = 18,000 mg-min/ m^3. One test of each type canister was continued for 6 hours (with no breakthrough); the CT achieved was 300 mg/ m^3 x 360 minutes = 108,000 mg-min/ m^3. The CT for the MUC is 0.005 mg/ m^3 x 60 minutes = 0.300 mg-min/ m^3.

The PAPR systems were subjected to a dynamic test wherein the facepiece was donned on a manikin headform that was connected to a breather pump. The motor blower, with appropriate cartridges attached, was powered to supply filtered air into the breathing room of the facepiece. The air flowed from the facepiece into the orinasal mask (nosecup), then through the exhalation valve to the outside. The entire setup was enclosed in an exposure chamber of approximately 100-liter volume. The breather pump pulled air from the orinasal mask and discharged the same air back into the mask, then it was discharged through the exhalation valve. The MINICAMS was connected to a port in the eye area of the headform, such that it sampled air supplied by the motor blower. Because the blower circulated air through the respirator at a rate of 170 L/min, a makeup air supply contaminated with Sarin was necessary. Makeup air was supplied at 90 L/min, with a concentration of 300 mg/ m^3 . Because clean air from the PAPR discharge diluted the makeup air, the effective concentration was not 300 mg/ m^3, but approximately 158 mg/ m^3. The volume of makeup air, 90 L/min, also was discharged from the chamber at the same rate through M18 scrubber filters. The pressure inside the chamber was

measured with a Magnehelic gauge; the pressure was 1-2 inches water, indicative of the resistance of the scrubber filters. The flow of air through the PAPR (6 cfm) caused positive pressure inside the respirator, which was not over breathed by the breather pump.

c. Number of Tests

Three complete PAPR systems from each manufacturer were tested against Sarin vapor. A system consisted of the facepiece, the breather tube, the motor blower with attached cartridges, and the battery power pack to operate the blower. In order to evaluate the cartridges as entities, a sample of 22 cartridges from each manufacturer was obtained. This number, 22, represents 90% reliability at 90% confidence level when no failure occurs amongst the 22 items. If a PAPR system exhibited a failure (allowed agent breakthrough), one can reasonably assert with 90% confidence that the failure occurred in some other component of the system than the cartridges.

d. Test Apparatus

The PAPRs and cartridges were tested against Sarin in apparatus consisting of vapor generator, test chamber, and MINICAMS agent detector. A gas chromatograph was used to determine the challenge concentration. A breather pump was used to simulate breathing while testing the PAPRs. Each component of the system is described separately below.

(1) Vapor generator. A 2-liter glass reservoir held a quantity of high-purity (CASARM-Grade) liquid Sarin maintained at constant temperature by a circulating water bath. A metered stream of dry air passed into the reservoir to sparge vapors out of the reservoir. The sparge flow rate was less than one liter per minute, and could be varied in order to adjust the Sarin concentration in the mixing chamber. The flow of Sarin-air was combined with a flow of 90 L/min dilution air at 50% relative humidity from a Miller-Nelson Humidity-Flow-Temperature Control System (Monterey, CA). The mixing chamber is a vessel that contains three perforated baffle plates to assure efficient mixing. The effluent from the mixing chamber was continuously monitored by a hydrogen flame emission detector; if the concentration of Sarin in the mixing chamber changed, it could be readjusted by changing temperature or air flows of the sparge or dilution air. The concentration of Sarin was determined by drawing a one-liter sample of air from the mixing chamber through a glass impinger containing isopropanol, measured by a wet test meter, and analyzing the solution for Sarin by gas chromatography (Hewlett Packard Model 5890, Wilmington, DE). The scrubbing efficiency of this type of impinger is greater than 97%. This is a standard Army test method. This vapor generator was used for testing both the PAPR systems and the cartridges.

(2) PAPR Test chamber. The test chamber for the PAPRs was a Plexiglas® box of approximately 100 liters volume, with removable front panel, and four legs to allow air to flow through the fume hood under the chamber. A headform, onto which the PAPRs were mounted for testing, was attached to the back wall of the chamber. A tube from the mouth area of the headform passed through the back wall of the

chamber and connected to a breather pump. A small tube connected the eye area to a remotely located Laboratory MINICAMS. The headform was equipped with a peripheral seal (inflatable bladder) that was inflated with 3 lbs of air to assure a tight seal between the headform and the facepiece of the PAPR. A port was provided in the wall of the chamber to introduce makeup air (vapor challenge). Two outlet ports were connected to M18 scrubber filters. A small port connected to a Magnehelic Gauge to measure the pressure inside the chamber.

(3) Cartridge Test Chamber. The test chamber for the cartridges was fabricated of stainless steel, cylindrical form, with one end removable. The removable end had a NATO thread adapter inside onto which the cartridges were fixed to be enclosed inside the test chamber for challenge with Sarin vapor. The outlet of the chamber was connected to a scrubber filter and rotameter to a vacuum source that generated a constant flow through the cartridge. A MINICAMS was connected to the tubing between the outlet port and the scrubber filter to detect any breakthrough of Sarin. Since the 3M cartridge was larger and had a proprietary thread, a special chamber was fabricated to test these cartridges.

(4) Breather pump. The military Breather Pump E1R1 (Jaeco-Stewart, Inc., Bethel, CT) was used to simulate breathing through the PAPRs. The flow rate produced by the pump begins at zero liters per minute at the beginning of the piston stroke, rises to a maximum (peak) flow rate at the top of the curve, and falls back to zero at the end of the stroke. The two flow characteristics of this pump that are of primary importance in filter testing are the minute volume, or average flow per minute in liters, and the peak flow. The minute volume can be adjusted up to a maximum of 52 liters per minute, whereas the strokes per minute (breaths) is fixed at 36. The peak flow is determined by the minute volume flow. The peak flow is checked with a calibrated Orifice Meter E5, which consists of a short tube with an orifice transverse, a side arm containing a rubber check valve connected to a 2-liter ballast bottle which in turn is connected to a manometer. The meter is calibrated by determining the manometer readings over a range of flow rates through the orifice, and constructing a regression curve. The peak flow for the minute volume flow of interest (approximately pi times the volume flow) is then read from the curve, and can be used with the orifice meter to check the pump flow. The peak flow rate of the pump is about 78 liters per minute at the flow of 25 liters per minute, about half the flow generated by a PAPR blower assembly. Because of the sinusoidal flow pattern, penetration of a filter will occur somewhat sooner using a breather pump than when using constant flow through the filter.

(5) MINICAMS. The MINICAMS, a mini chemical agent monitoring system (O.I. Analytical, Birmingham, AL), is an automated air monitoring and alarm system based on sample collection on solid sorbents to concentrate the contaminant, desorption onto a temperature programmed capillary gas chromatograph column, and detection based on flame ionization or flame photometry. This system is controlled by PC computer, and is capable of detecting and quantitating concentrations of chemical agents,

including Sarin, at levels below the 8-hour Time Weighted Average (TWA) concentrations (AR 385-61). The MINICAMS was standardized by injecting standard solutions of Sarin-isopropanol. For this project, the detection limit of the MINICAMS was established at 0.00007 mg/m^3.

e. Procedures

(1) PAPR System Test. The PAPR was mounted on the headform in the test chamber. The breathing tube from the PAPR was connected to the PAPR blower assembly. The appropriate cartridges were installed onto the PAPR and the blower assembly set on the floor of the test chamber. The power cable between the blower assembly and the battery pack was connected, with the battery pack outside the test chamber. The blower assembly air flow was set to 170 L/min, checked and the front panel of the test chamber closed. The PAPR was checked for leakage by using the ATI TDA 99-M Respirator Tester (aerosol) with the blower and the breather pump operating. If there was no leakage, the Sarin-air mixture was passed into the test chamber. The concentration of Sarin was measured at the beginning of each test and each hour for the long tests. The breather pump was operated to draw air from inside the respirator at an average rate of 25 liters per minute. The air drawn in by the pump was discharged back into the breathing room of the facepiece, then out the exhalation valve into the test chamber. The MINICAMS was used to detect any penetration of Sarin into the respirator.

(2) Filter Cartridge Test. The test apparatus was operated under the conditions set out in the following section. The cartridge was mounted in the test chamber, and the chamber was closed and connected to the test apparatus. At the beginning of the exposure, if the MINICAMS indicates a leak around the filter, the agent flow to the test chamber was turned off, the cartridge reseated, and the test restarted. At the conclusion of the test, the agent flow to the test chamber was turned off, the cartridge removed, and a fresh cartridge installed for the next test. The challenge concentration was checked before starting the next test, or hourly when the test was run longer than one hour.

f. Test Conditions

(1) Conditions for testing PAPR systems:

Volume of challenge concentration generated	90 L/min
Peak concentration of challenge Sarin	300 mg/m^3
Breakthrough concentration limit	0.0001 mg/m^3
Total test time if break-through is not observed	60 minutes
Precondition of cartridges	25°C/50%RH,6 hrs
Temperature of test chamber	25±3°C
Flow of air through PAPR blower	170 L/min
Average flow of breather pump	25 L/min

(2) Conditions for testing cartridges:

Volume flow rate of challenge concentration	90 L/min
Peak concentration of challenge Sarin	300 mg/m^3
Breakthrough concentration detection limit	0.0001 mg/m^3
Total test time if breakthrough is not observed	60 minutes
Precondition of cartridges	25°C/50%RH, 6hrs
Temperature of test chamber	25±3°C
Relative Humidity of test air	50±5%

g. Air Flow Rates for Cartridge Tests

The cartridge test chamber used a constant flow rate through the cartridge. Based on the test procedures developed for the DP application for a PAPR rated at 6 cfm and using only one cartridge, the cartridge was tested at 85 L/min. If the PAPR has two Cartridges, the test flow was 85/2 L/min, or 43 L/min, and if the PAPR has three cartridge, the test flow was 85/3 or 28 L/min. The following Table identifies the flow rates used for the cartridges associated with each PAPR.

Table 2. Flow Rates Used for PAPR Cartridge Tests

PAPR	Cartridges	NIOSH Approved Test Number	Flow Rate, L/min
3M GVP-4M w/GVP-443	1	TC-23C-1478	85
MSA OptimAir™ 6A w/GMC-H	2	TC-23C-1056	43
KASCO Venus T8 w/ZAP3	2	TC-23C-1811	43
Racal™ BE7 w/AEP3	3	TC-23C-0647	28
Survivair® 540084 w/158300	3	TC-23C-1053	28
Neoterik TF3 w/NP2532	3	TC-23C-1529	28

h. Results and Discussion

None of the 22 *cartridges* of any make tested against Sarin showed any penetration at the end of one hour. None of the cartridges of any make (one each) tested against Sarin for 6 hours showed any penetration.

None of the three PAPR *systems* of each make tested against Sarin showed any penetration at the end of one hour. None of the PAPR systems of any make (one each) tested against Sarin for 6 hours showed any penetration.

The test results indicate that the cartridge of each manufacturer tested against Sarin, if used with the associated PAPRs according to the manufacturers' instructions, will protect against the MUC of Sarin for at least one hour and probably more than 6 hours. It must be noted that the seal between the facepiece and the wearer's face must be tight, and that wearers must be trained in achieving a high protection factor when donning the respirator.

It must be noted that if any PAPR is contemplated to be used in atmospheres of mustard (HD) or Lewisite (L), regardless of the MUC calculated, the respirators should not be worn when concentration levels of either HD or L exceed 0.003 mg/m^3. This is the concentration where carcinogenic effects start to occur.

5. Protection Factor Testing

a. Test Methodology

(1) Test Description.

The six PAPR's mentioned above were tested over a six week period with military volunteers challenged with a corn oil aerosol. A total of 24 different subjects for each PAPR were used in the test. Prior to testing, each test volunteer was given an orientation in which the PF test was explained by ERDEC personnel and a volunteer agreement was signed by each test volunteer. A total of 96 trials were conducted with the sample broken down into the following major concepts:

1) PAPR Unblown (Sampled from visor, *unblown* refers to negative pressure)
2) PAPR Blown (Sampled from visor, *blown* refers to positive pressure)

All volunteers had anthropometric data taken of their facial features and then given a PAPR and asked to wear their normal clothing (Battle Dress Uniform (BDU)). The test volunteers were then led into the aerosol test chamber, 8 at a time, by ECBC personnel, hooked up to their photometer stations, and asked to perform a standard Army PF Test. The PF Test consisted of a standard ten exercise (ten minutes total) routine devised to stress the face seal of the PAPR. In the test, volunteers were asked to perform the following ten exercises for one-minute each:

1. Normal Breathing
2. Deep Breathing
3. Turn Head Side to Side
4. Move Head Up and Down
5. Recite the Rainbow Passage (Reading a paragraph aloud to stress talking)
6. Sight the Rifle
7. Reach for the Floor and Ceiling
8. On Hands and Knees, Turn Head Side to Side
9. Facial Expressions
10. Normal Breathing

The test equipment operator monitored and communicated with the test volunteers on when to start an exercise, finish an exercise, and exit the aerosol chamber. All

exercises were completed by the test volunteers without the intervention of test personnel*.

All raw data was collected by a computer-based system and stored on a flexible diskette for later analysis.

(2) Corn Oil Test Facilities.

A challenge aerosol concentration of approximately 20-40 mg/m³, polydispersed corn oil aerosol having a mass median aerodynamic diameter (MMAD) of 0.4-0.6 microns, was generated in a 10-ft X 10-ft X 32-ft test chamber. The test chamber challenge aerosol was generated by atomizing liquid corn oil at room temperature using a Laskin nozzle. The Laskin nozzle produced a coarse aerosol cloud, which was directed into an impaction plate to remove the larger particles and yield an aerosol in the desired size range. The concentration aerosol from the generator was diluted with filtered ambient air to control the challenge aerosol concentration in the test chamber.

A 6-decade, 45 degree off-axis light-scattering laser photometer, sampling at a flow rate of 1-2 L/min, was used to quantify the amount of light scattered by the challenge and the in-mask corn oil aerosols. For a given particle size, the quantity of scattered light is proportional to the aerosol concentration. The photometer converted the quantity of scattered light to a voltage, which was then digitized and recorded by a microcomputer.

The PAPR sampling port was connected to the test chamber sampling port with flexible silicone tubing to measure the amount of aerosol penetrating the mask. A Tygon® sampling tube line was connected from the test chamber sampling port to the photometer to determine the challenge aerosol concentration.

(3) Data Analysis

Mask performance was quantified in terms of a protection factor (PF). The PF was calculated by determining the ratio of the challenge aerosol concentration to the in-mask aerosol concentration as quantified by the voltage output from the photometer. A PF was calculated for individual exercises (PF_i). The individual PFs were then used to calculate an overall PF for a subject (PF_o) as follows:

$$PF_o = n(\sum_{I\text{-}1 \text{ to } n} 1/PF_i)^{-1}$$

where n is the number of exercises. The overall PF provides a time-integrated measure of the protection afforded. It is somewhat analogous to calculating the total resistance of resistors in parallel in an electronic circuit. The PF_0 is affected most by the lowest PFs. Under the conditions of this test and the sensitivity of the photometer, the maximum PF that can be reported is 100,000. The PFs were calculated by a computer and stored to disk.

* Every week 24 new volunteers for each PAPR were used. Sizes for the six different PAPRs were "one-size-fits-all".

(4) Interpreting PF Summary Sheets

Overall PF is calculated by taking the inverse of the individual Protection Factors for each exercise, summing the values and finding the average. The inverse of this average is the overall PF.

The test data is summarized in Tables 3a, 3b, 4a, and 4b. The first column lists the lower limit of each range of PF computed. The second column is the number of test occasions which resulted in calculated PF within the range. The third column presents the total number of test occasions which resulted in a PF below the lower limit of the range, presented as a percentage of the sample population. The fourth column is like the third, but presents the percentage which are above the lower limit of the range shown. The final PF range shown is over 100,000, but the current data acquisition system cannot measure PF over 100,000, so it truncates the data and puts all the remaining occasions in the final range.

b. Results And Discussion

Analysis of the data was completed for each NIOSH approved PAPR model using pass/fail percentages at selected PF levels. Each PAPR was tested in two modes: unblown and blown. Unblown mode is when the blower which supplies filtered, forced air to the facepiece is turned off, and blown is when the blower is turned on. The unblown mode simulates a blower failure or a battery failure during use, and addresses the question; Does the PAPR still provide adequate protection in a negative-pressure mode?

In this PF test, each test subject (24 subjects) performed the standard ten exercise routine twice in each mode for a total of 96 trials for each PAPR model. Where fewer occasions are reported it is because the test data was invalidated for some reason unrelated to PAPR design. Because these are commercially available PAPRs there were no Army requirements established for these respirators. Therefore, we took the conservative approach and reported the data in pass and fail percentages for each PAPR configuration at selected PF levels. The analyzed data is provided in Tables 3a and 3b for unblown modes and in Tables 4a and 4b for blown modes.

Because these PF tests were performed to provide useful information to the first responder operating in a chemical agent environment, pass percentages based on U.S. Army requirements were included in the summary tables. The U.S. Army specifies that for this standard PF test, performed with negative-pressure (unblown mode) respirators, the sample population must meet 75% pass rate at 6667 PF and 88% pass rate at 1667 PF. For positive-pressure (blown mode) respirators, the U.S. Army requirement is that 100% of the sample population must meet 10,000 PF.

Tables 4a and 4b show that all six PAPRs met the positive-pressure requirement of 100% pass at the 10,000 PF level. Tables 3a and 3b show that in the unblown, or negative-pressure mode, one PAPR model failed to meet the U.S. Army requirements. The PAPR made by Kasco had a pass percentage of only 47% at the 6667 PF level. This result is rather low and may be attributable to the suspension system used by the Kasco.

During the PF test, several of the head harness buckles came free or were loose from the facepiece causing unnecessary leakage in the unblown mode. Further testing may be necessary to aid in designing a better suspension system.

Table 3a. Final PF Results, PAPRs (Unblown Mode)

PF Range	3M PAPR (unblown)			KASCO PAPR (unblown)			MSA PAPR (unblown)		
	No. of Occasions in Range	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*	*No. of Occasions in Range*	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*	*No. of Occasions in Range*	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*
10-49	0	0	100	0	0	100	0	0	100
50-99	0	0	100	0	0	100	0	0	100
100-499	0	0	100	0	0	100	1	2	98
500-999	0	0	100	0	0	100	2	6	94
1000-1666	1	2	98	2	4	96	0	6	94
1667-1999	0	2	98	1	7	93	1	8	92
2000-4999	0	2	98	1	9	91	0	8	92
5000-6666	0	2	98	15	42	58	1	10	90
6667-9999	0	2	98	5	53	47	2	15	85
10000-19999	2	7	93	13	82	18	5	25	75
20000-49999	3	13	87	6	96	4	7	40	60
50000-99999	9	33	67	1	98	2	11	63	38
100000(+)	31	100	0	1	100	0	18	100	0
No. of Trials	46			45			48		

Table 3b. Final PF Results, PAPRs (Unblown Mode)

PF Range	NEOTERIK PAPR (unblown)			RACAL PAPR (unblown)			Survivair PAPR (unblown)		
	No. of Occasions in Range	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*	*No. of Occasions in Range*	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*	*No. of Occasions in Range*	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*
10-49	0	0	100	0	0	100	0	0	100
50-99	0	0	100	0	0	100	0	0	100
100-499	0	0	100	0	0	100	0	0	100
500-999	0	0	100	0	0	100	0	0	100
1000-1666	1	2	98	1	2	98	0	0	100
1667-1999	3	9	91	1	4	96	0	0	100
2000-4999	0	9	91	0	4	96	0	0	100
5000-6666	2	13	86	3	11	89	1	2	98
6667-9999	0	14	86	3	17	83	0	2	98
10000-19999	3	20	80	1	19	81	0	2	98
20000-49999	0	20	80	3	26	74	0	2	98
50000-99999	4	30	70	8	43	57	5	13	87
100000(+)	31	100	0	27	100	0	39	100	0
No. of Trials	44			47			45		

Table 4a. Final PF Results, PAPRs (Blown Mode)

PF Range	3M PAPR (blown)			KASCO PAPR (blown)			MSA PAPR (blown)		
	No. of Occasions in Range	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*	*No. of Occasions in Range*	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*	*No. of Occasions in Range*	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*
10-49	0	0	100	0	0	100	0	0	100
50-99	0	0	100	0	0	100	0	0	100
100-499	0	0	100	0	0	100	0	0	100
500-999	0	0	100	0	0	100	0	0	100
1000-1666	0	0	100	0	0	100	0	0	100
1667-1999	0	0	100	0	0	100	0	0	100
2000-4999	0	0	100	0	0	100	0	0	100
5000-6666	0	0	100	0	0	100	0	0	100
6667-9999	0	0	100	0	0	100	0	0	100
10000-19999	0	0	100	0	0	100	0	0	100
20000-49999	0	0	100	0	0	100	0	0	100
50000-99999	2	4	96	5	11	89	0	0	100
100000(+)	44	100	0	42	100	0	47	100	0
No. of Trials	46			47			47		

Table 4b. Final PF Results, PAPRs (Blown Mode)

PF Range	NEOTERIK PAPR (blown)			RACAL PAPR (blown)			Survivair PAPR (blown)		
	No. of Occasions in Range	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*	*No. of Occasions in Range*	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*	*No. of Occasions in Range*	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*
10-49	0	0	100	0	0	100	0	0	100
50-99	0	0	100	0	0	100	0	0	100
100-499	0	0	100	0	0	100	0	0	100
500-999	0	0	100	0	0	100	0	0	100
1000-1666	0	0	100	0	0	100	0	0	100
1667-1999	0	0	100	0	0	100	0	0	100
2000-4999	0	0	100	0	0	100	0	0	100
5000-6666	0	0	100	0	0	100	0	0	100
6667-9999	0	0	100	0	0	100	0	0	100
10000-19999	0	0	100	0	0	100	0	0	100
20000-49999	0	0	100	0	0	100	0	0	100
50000-99999	2	5	95	0	0	100	0	0	100
100000(+)	42	100	0	48	100	0	48	100	0
No. of Trials	44			48			48		

6. Conclusions

Overall, the six Powered Air Purifying Respirator Systems using the designated cartridges as described in this report will protect personnel against Sarin concentrations of 300 mg/m^3 for at least one hour and probably more than 6 hours. Protection Factor results indicate that the six PAPRs met U.S. Army requirements for positive-pressure respirators, however a problem may exist with the Kasco PAPR if worn in the negative-pressure or unblown mode.

Appendix A – References

1. Type Protocol for CRDEC Respirator Quantitative Fit Testing program, Log Number 4448. Maria B. Filinska, 19 Jan 89.
2. Type Protocol for CRDEC Individual Protective Equipment Quantitative Fit Testing program, Log Number 9209T. Alex Pappas, 9 Oct 92.
3. Annex Protocol for ERDEC Protection Factor Test with a Powered Air Purifying Respirator (PAPR), Log Number 9703A. Alex Pappas, March 97.
4. AR 50-6, Chemical Surety, 1 Feb 95.
5. AR 385-61, The Army Chemical Agent Safety Program, 28 Feb 97.
6. DA Pam 385-61, Toxic Chemical Agent Safety Standards, 31 Mar 97.
7. DACS-SF, Memorandum dated 11 Sept 96, subject: Policy for the Use of NIOSH-Certified Commercial Respirators with Chemical Agents.
8. SCBRD-ODR-S, MEMORANDUM DATED 15 May 1995, subject: Commercial Chemical Protective Clothing - Guidance For Preparing a Request.
9. DACS-SF, memorandum dated 7 May 1998, subject: Preparing a Request to Use Commercial Environmental Protection Agency Level B Clothing for Chemical Agent Operations.

Appendix B – Glossary

Airborne Exposure Limit (AEL)

The concentration of a chemical agent in air, in mg/ m^3, expressed as an 8-hour time weighted average (TWA), which is the average exposure limitation for a normal 8-hour workday and a 40-hour workweek to which nearly all unmasked workers can be exposed, day after day, without known adverse health effects. The AEL is equivalent to the permissible exposure limit (PEL).

Assigned Protection Factors (APF)

An Assigned Protection Factor is the level of protection that a particular type of respirator can be expected to provide 95% of the time. An APF of 10 means that type of respirator (if used properly) can be safely used in an atmosphere that has a hazardous concentration of up to 10 times the Permissible Exposure Limit (PEL) for that hazard. APF's are determined by the government or a standards organization. In the United States, the National Institute of Occupational Safety and Health (NIOSH) and the American National Standards Institute (ANSI) both establish APF's for various types of respirators. For example, a half face negative pressure air purifying respirator typically has an APF of 10. Most full face negative pressure air purifying respirators typically have an APF of 50.

Breather Pump

A pump used to simulate human breathing through a filter. The pump is a piston pump designed to begin the stroke at zero flow, rise to a maximum (peak) flow at midstroke, and decrease to zero at the end of the stroke. The resultant flow is sinusoidal, that is, shaped like a sine wave when plotted. The pump stroke can be adjusted to change the volume of air per stroke over a finite range; some pumps are capable of changing the number of strokes per minute.

CT

Symbol for Concentration times Time. A method for expressing the protection of a filter in terms of quantity of agent adsorbed. It is calculated by multiplying the challenge concentration (in mg/ m^3) by the time to breakthrough (or the total challenge time) in minutes. The unit is mg-min/ m^3.

CASHPAC

U.S. Army Chemical Agent Safety and Health Policy Action Committee.

CASARM-Grade

Chemical Agent Standard Analytical Reference Material maintained by the U.S. Army for calibration of monitoring and analytical equipment.

Fit Factor (FF)

A Fit Factor is a number that is the direct result of a quantitative respirator fit test. It is a measurement made by an instrument during a simulation of workplace activities or scenarios. It is expressed as the challenge aerosol concentration outside the respirator divided by the challenge aerosol concentration that leaks inside the respirator during a Fit Test.

HD

The military symbol for mustard, a vesicant (blister) chemical agent. The chemcal name for HD is bis(2-chloroethyl)sulfide.

IDLH

Immediately dangerous to life and health.

L

The military symbol for Lewisite, a vesicant (blister) chemical agent. The chemical name for L is dichloro-2-chlorovinylarsine.

Maximum use concentration (MUC)

Commonly determined as the threshold limit value (TLV) or PEL or AEL times the assigned protection factor (APF) of a respirator. The MUC is the maximum concentration of chemical agent in which the respirator is allowed to be used. However, no matter what MUC is calculated, no respirator can be used when concentrations of HD (mustard) or L (Lewisite) are above 0.003 mg/m3, because of the carcinogenic properties of HD and L.

MINICAMS

Trade name for a chemical agent detector in which the agent is adsorbed from a specified volume of air onto an adsorbent tube which is then desorbed into the injection port of a gas chromatograph for analysis (quantitation). The acronym stands for "Mini chemical agent monitoring system."

PAPR

Powered Air–Purifying Respirator with a tight or loose fitting facepiece with some kind of hose connected to a turbo unit or blower. The blower produces 4-6 cubic feet per minute of flow into the facepiece.

Sarin

An organophosphorus nerve agent, known by the military symbol GB. The chemcal name is isopropyl methylphosphonofluoridate. GB reacts with the enzyme cholinesterase, thus interfering with the transmission of nerve impulses.